Neutrino Physics

CPAD Instrumentation Frontier Workshop

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P5 Science Drivers

Pursue the physics associated with neutrino mass

Explore the unknown: new particles, interactions, physical principles

Science Impacts

Precision tests of the three-flavor neutrino paradigm

Expand the regime of neutrino measurements in source, energy and intensity

Search for **BSM** physics

Science Impact #1: Precision tests of the three-flavor paradigm

Precision measurements of neutrino mixing

Neutrino unitarity

Measure the absolute neutrino mass

Determine the nature of neutrino mass (i.e., Dirac or Majorana, NLDBD)

Measure the Majorana phases

Science Impact #2: Expand the regime of neutrino measurements in source, energy, intensity (CνB, solar, SN, HE astrophysical)

Discover the cosmic neutrino background

Measure supernova burst neutrinos in all three flavors in real time

Measure diffuse supernova neutrino

Measure lower-energy neutrinos (e.g. pp solar, thermal solar) in real time with high statistics

Solar neutrino measurements (e.g. solar - reactor Δm_{12}^2 tension)

Measure neutrinos at macroscopic energies from cosmic distances

Science Impact #3: Searches for physics beyond the Standard Model [in neutrino detectors]

Neutrino magnetic moment

Sterile neutrinos

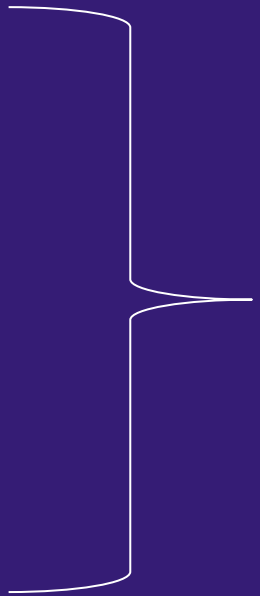
Neutrino tridents

Proton decay

Dark matter, axions,...

Millicharged particles

...



Both:

- BSM in the neutrino sector
- BSM in other sectors that can be done with neutrino detectors

What is generally desired for neutrino detectors?

Of course emphasis depends on specific aim, but frequently:

- Large mass (at low cost)
- Resolution for reconstructed quantities:
  energy, momentum, time, particle ID… high granularity
- Energy threshold (range relevant to physics)
- Low background

Tried to turn the question around:
what transformative physics do we want to do with neutrinos?
(or neutrino detectors) What do we need to do it?

Information comes from neutrinos over ~25 orders of magnitude in energy!

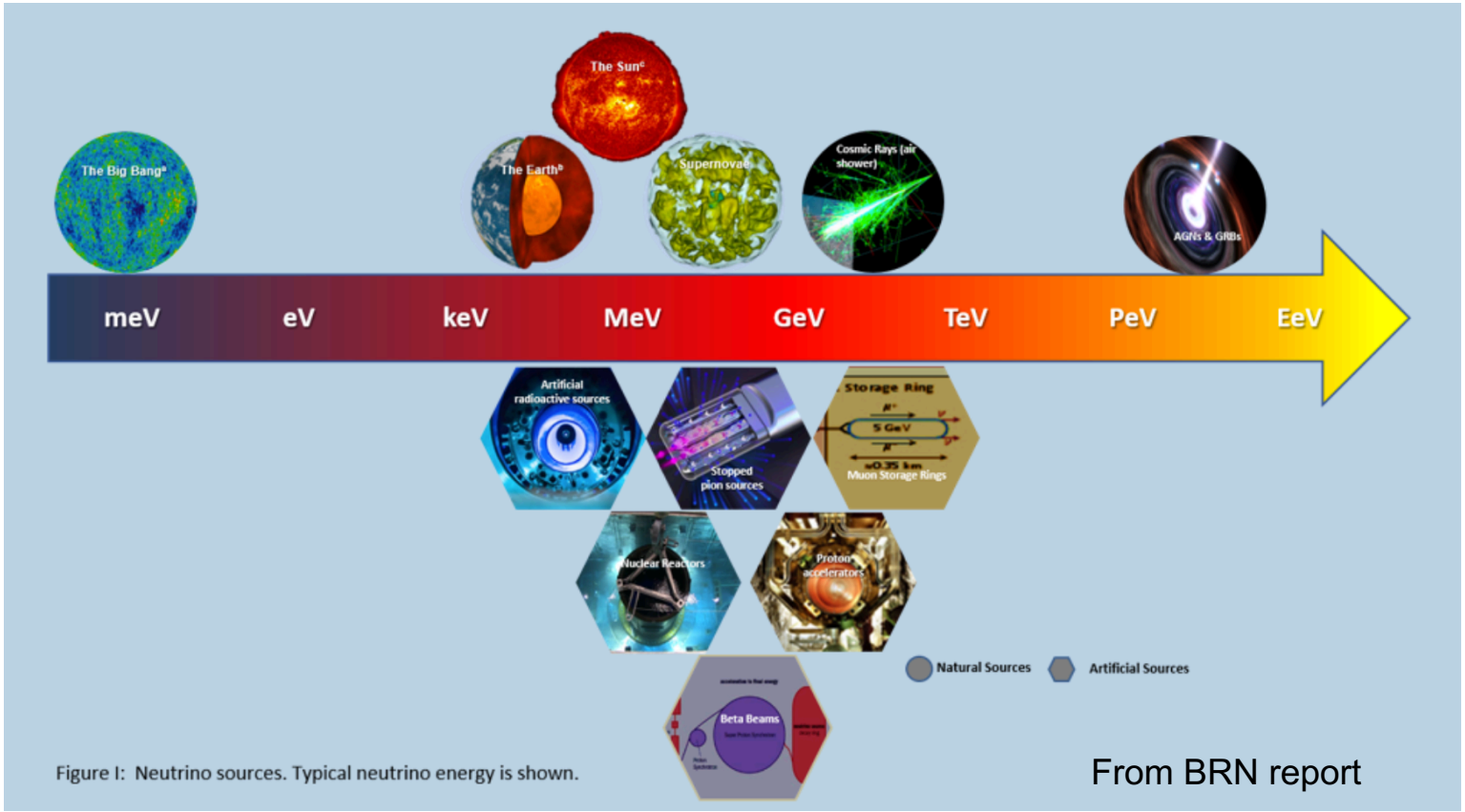
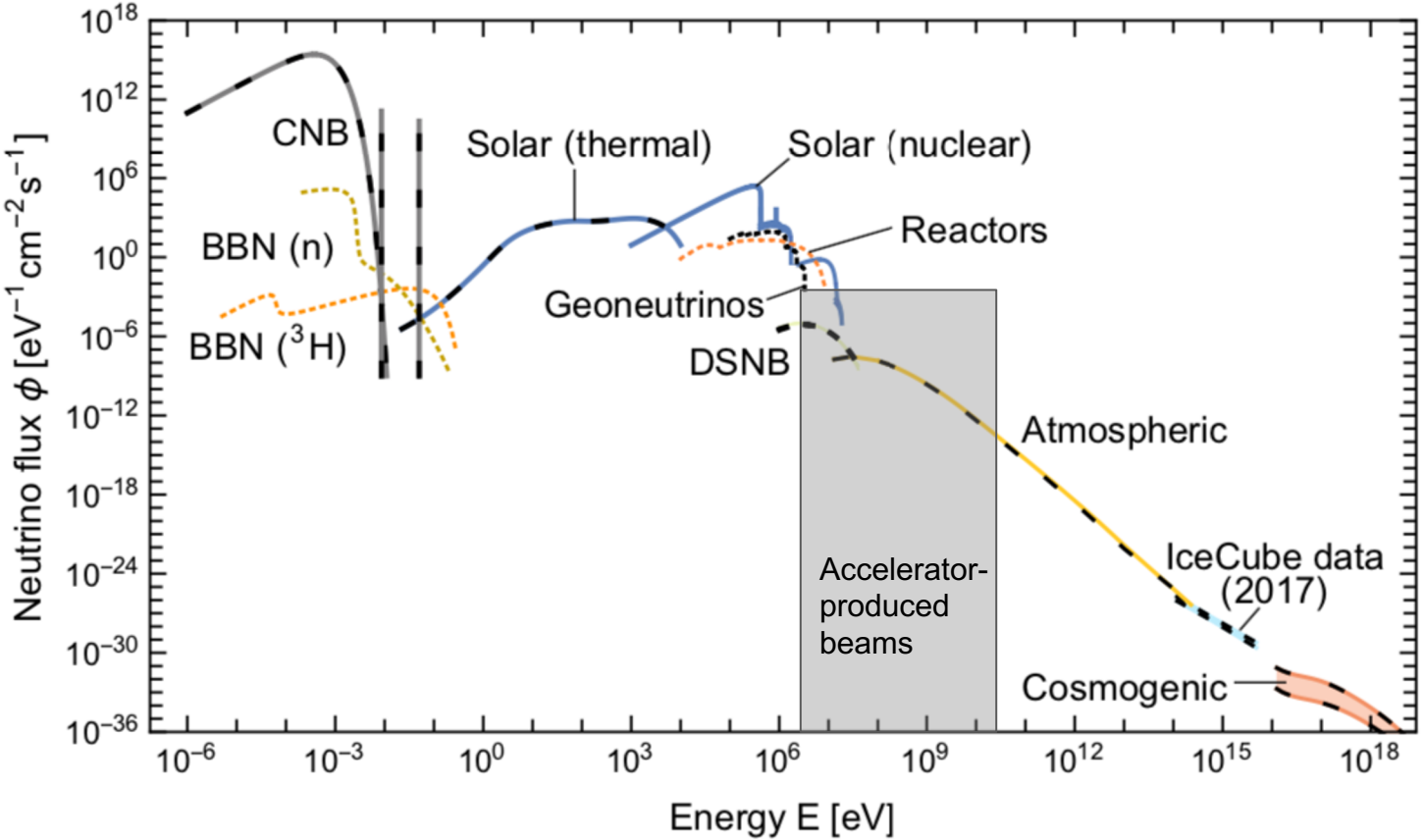


Figure I: Neutrino sources. Typical neutrino energy is shown.

From BRN report

Information comes from neutrinos over ~25 orders of magnitude in energy!

Grand Unified Neutrino Spectrum at Earth
Edoardo Vitagliano, Irene Tamborra, Georg Raffelt. Oct 25, 2019. 54 pp.
MPP-2019-205
e-Print: arXiv:1910.11878 [astro-ph.HE] | PDF



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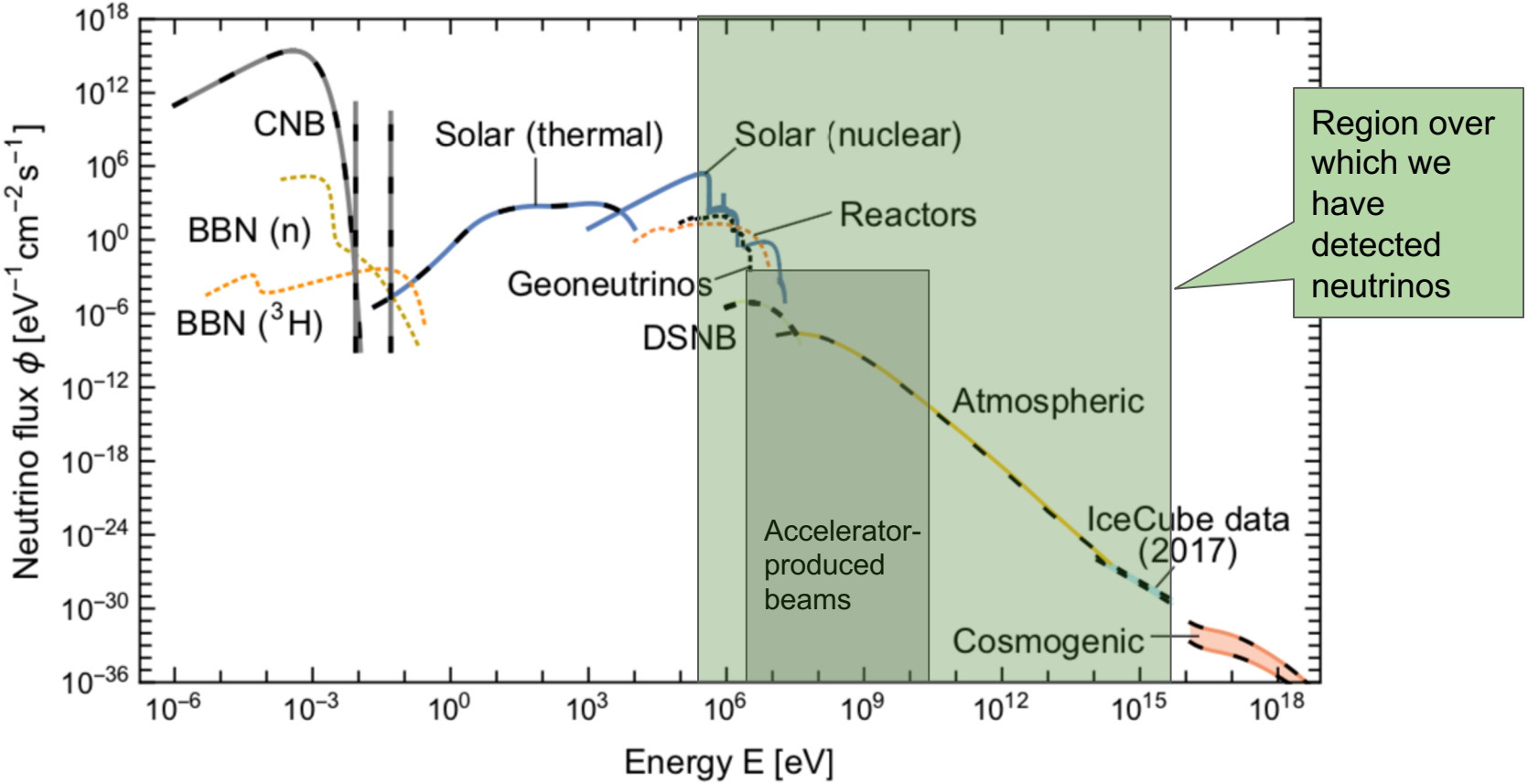
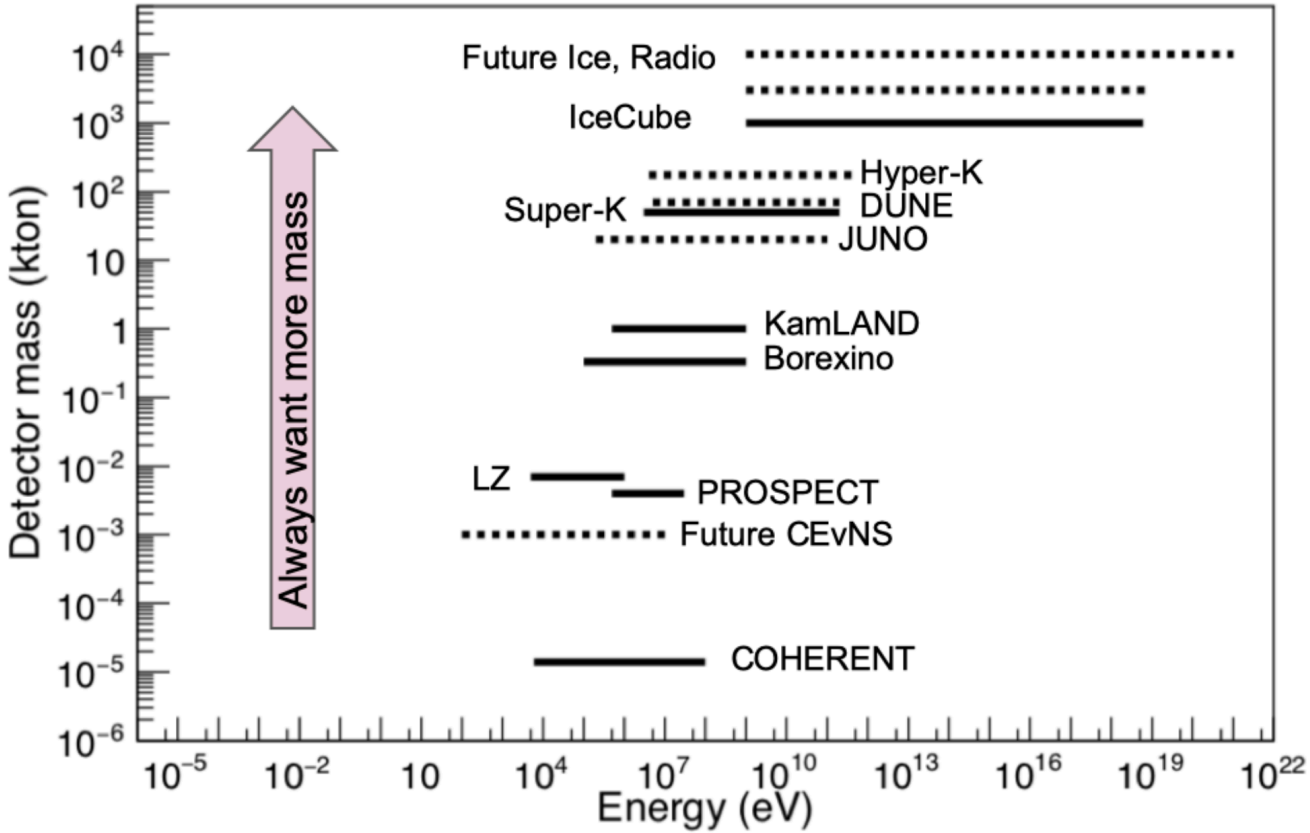


Neutrino detector masses and sensitive energy ranges



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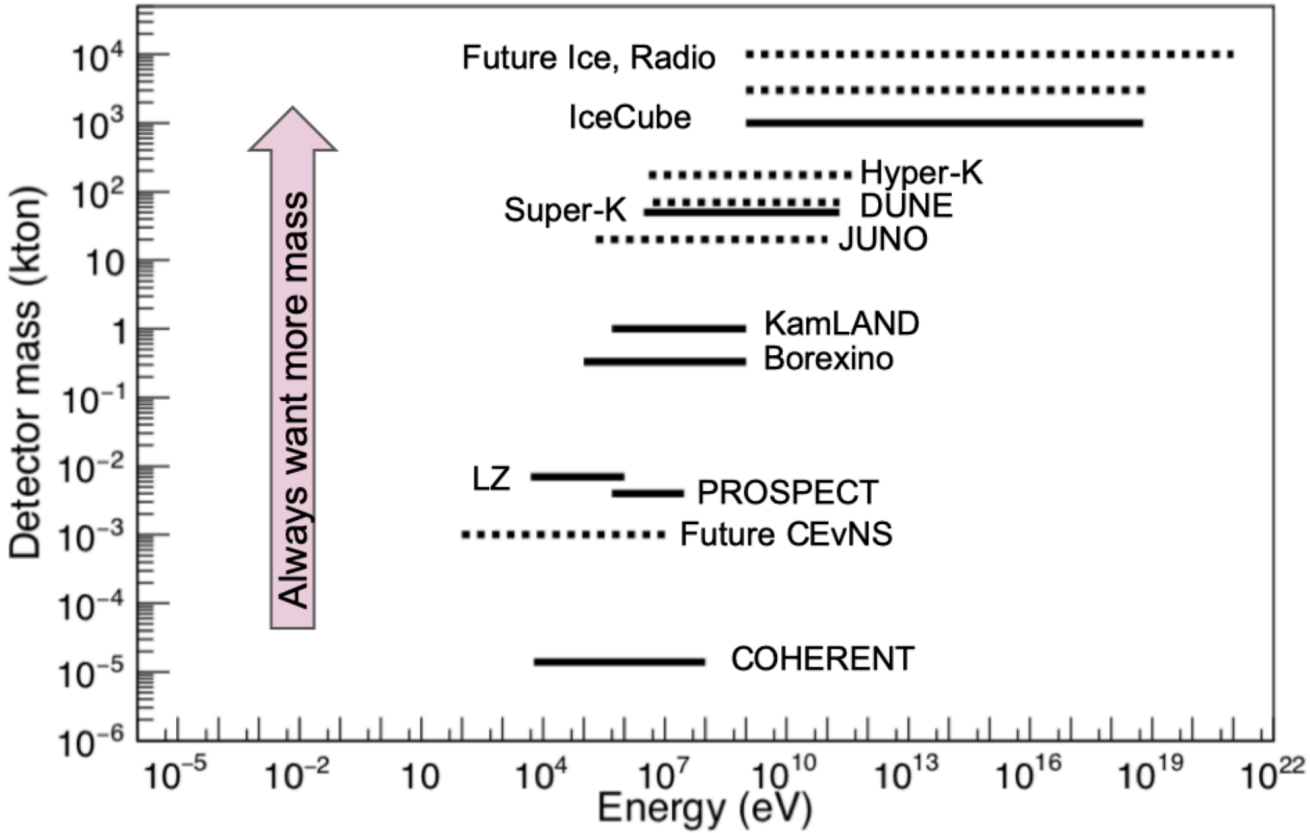
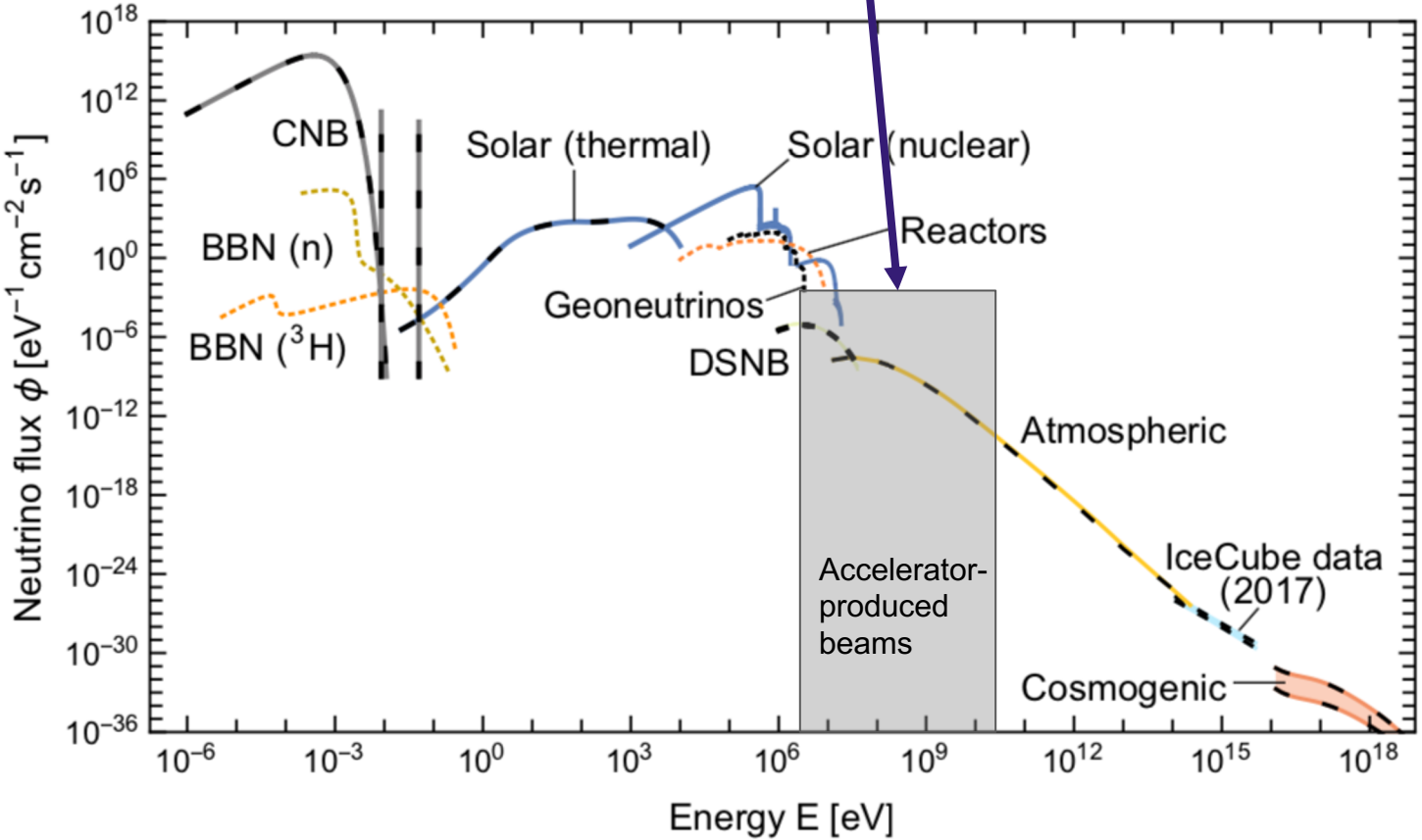


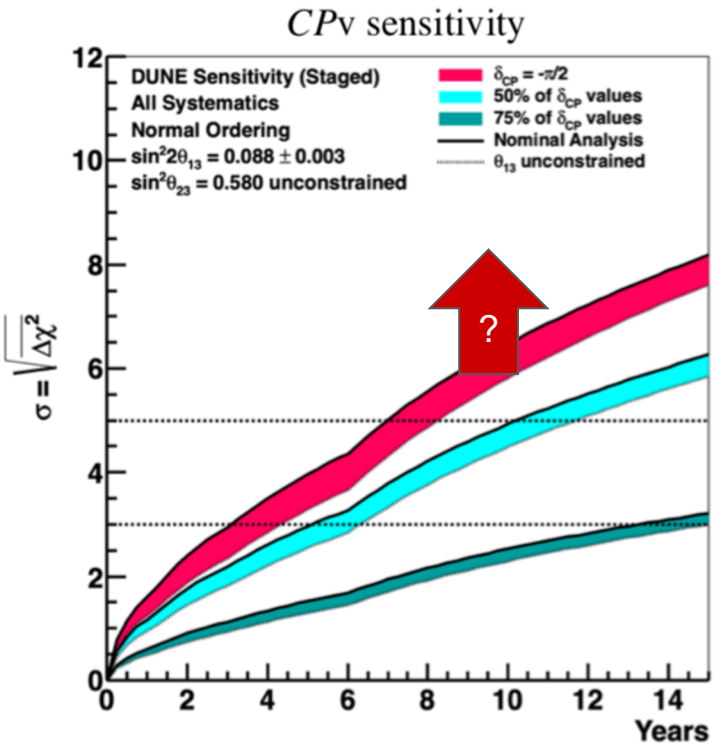
A few examples...

First, here, in the category of “precision measurements of the 3-flavor sector”...



Many things will improve with
better technology, but it's not trivial
to quantitatively tie detector improvements
to specific oscillation parameter precision
(work already underway!)
… improvements are likely
to be incremental

Will instead highlight some items which will
broaden the physics program…
Enable detection of neutrinos
in new regimes, with new capabilities

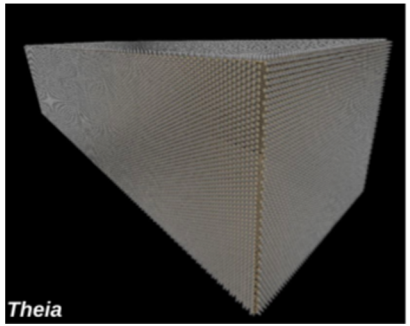


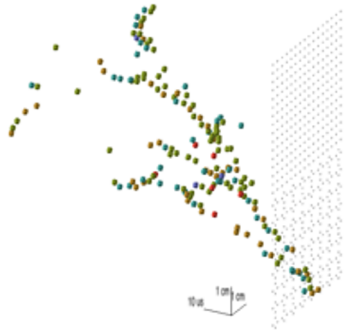
Novel detector technology for oscillation experiments

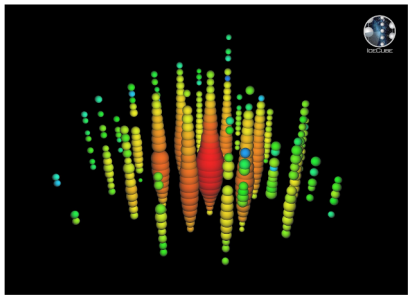
Precision measure-ments of neutrino mixing

Measure appearance and disappearance of accelerator and natural neutrinos

Novel charge detection, light production and detection; magnetization





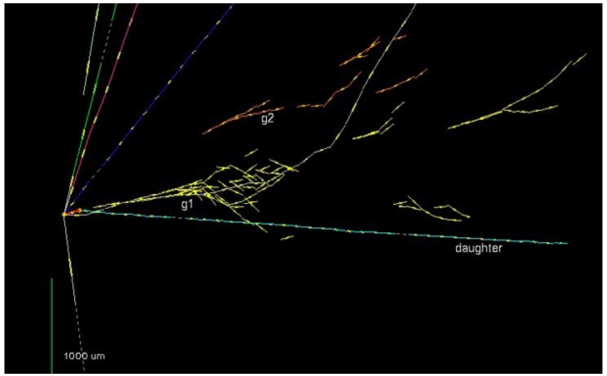


High-statistics tau neutrino appearance in real-time detectors

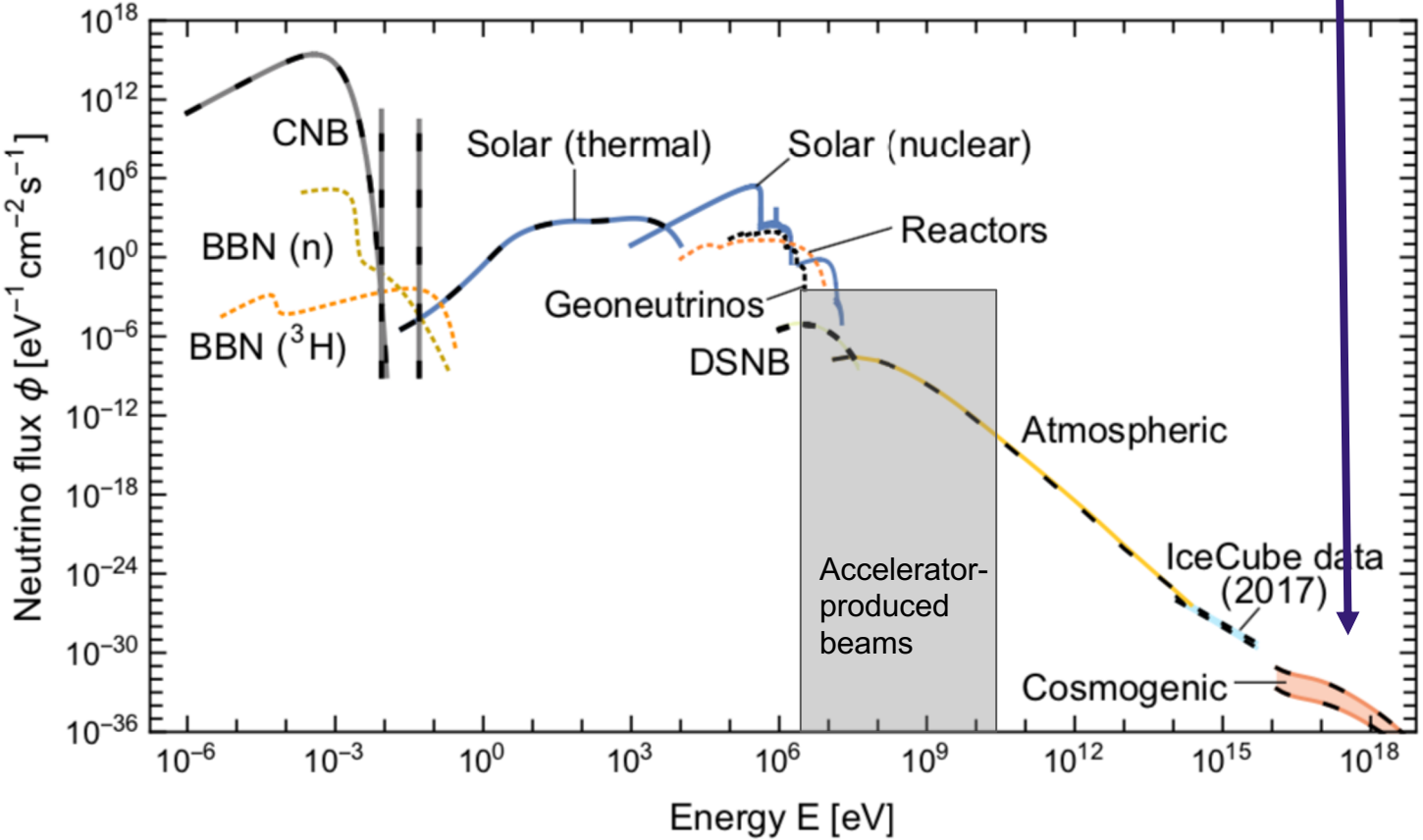
Neutrino mixing matrix unitarity

Measure tau neutrino appearance in real time with high efficiency

Resolve short tracks (0.1 mm at 10 GeV) in 10 kt detectors



The ultra-high-energy frontier

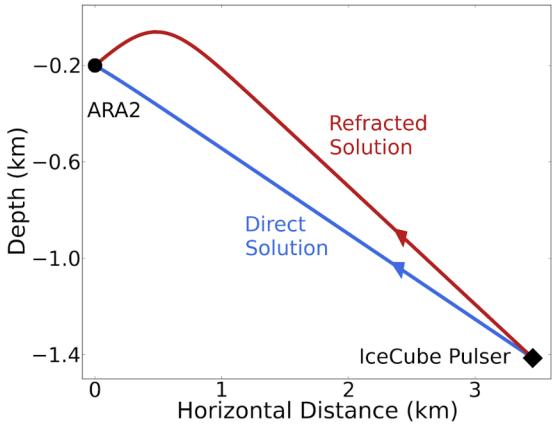


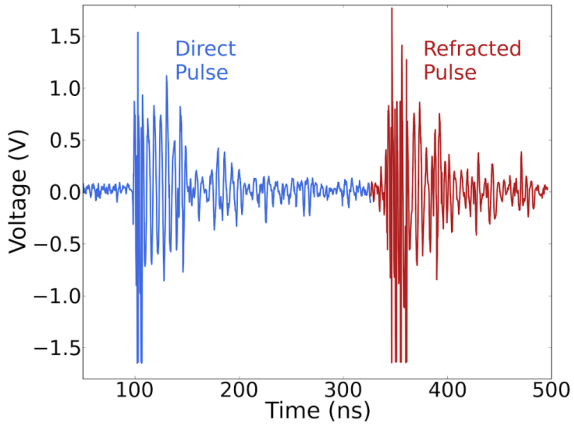
Ultra-high energy neutrinos

Measure neutrinos at macroscopic energies from cosmic distances

Sensitivity to neutrino fluxes ~1/km^2/ decade at low energy threshold

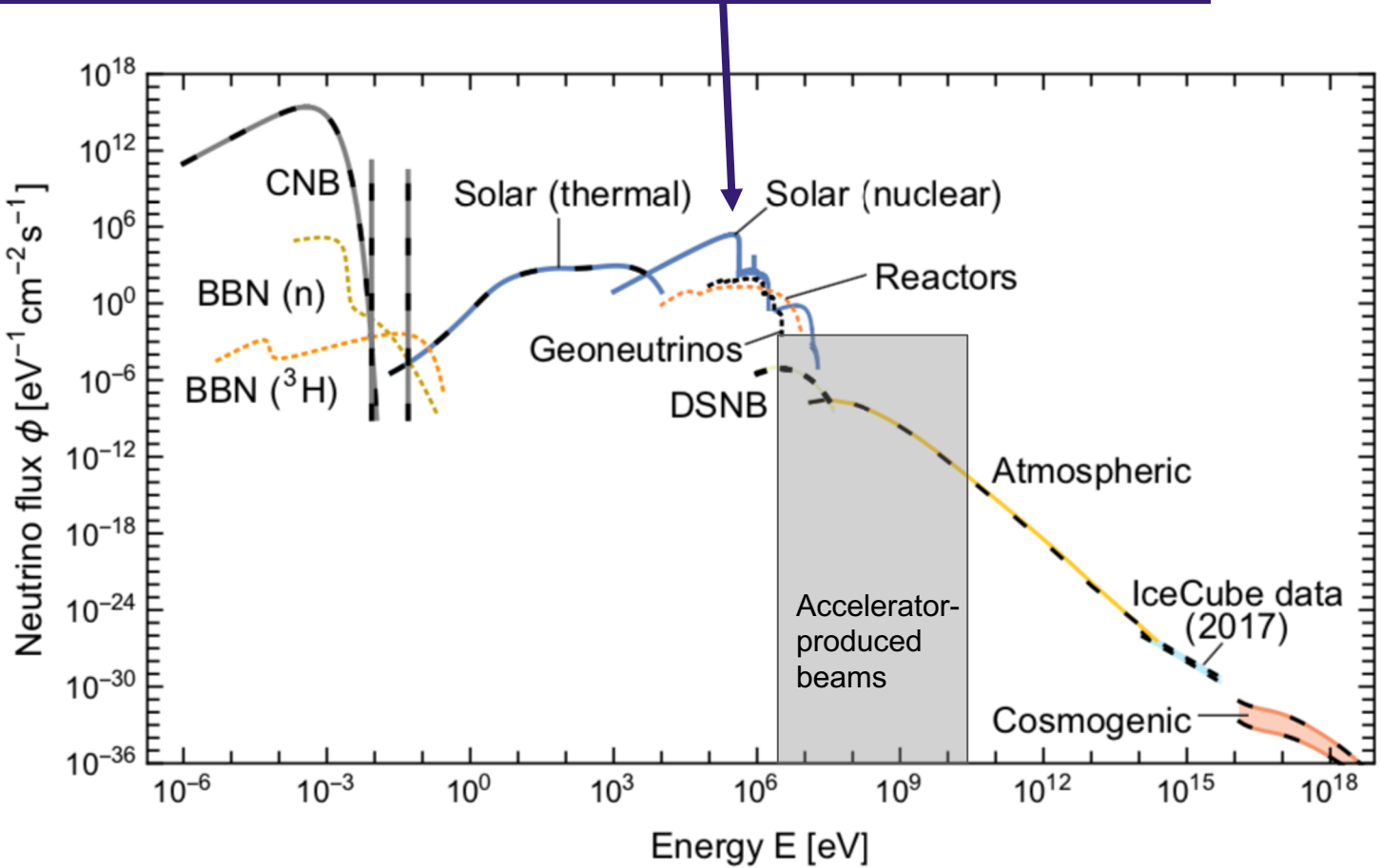
Low power (<<1 W) digitizers sampling at >3 GHz, triggering at O(1) S/N





Calibration pulser mimicking a neutrino signal from ARA

Few to few tens of MeV regime: solar and supernova neutrinos

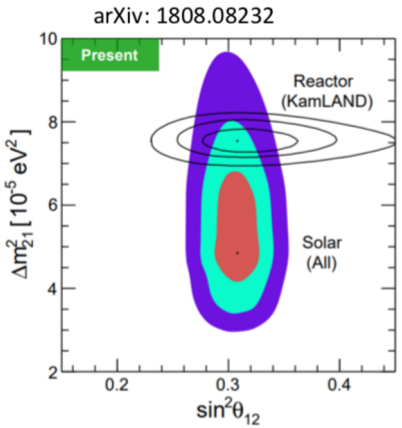


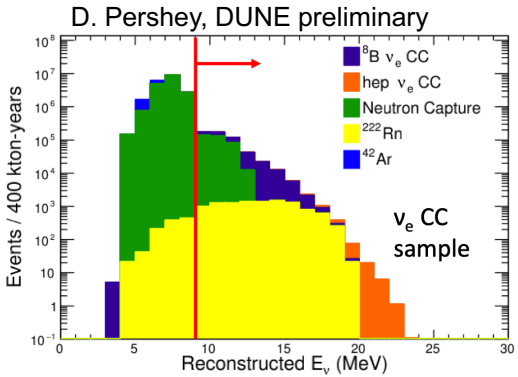
Improved solar neutrino measurements

Resolve solar/ reactor dm^2 tension

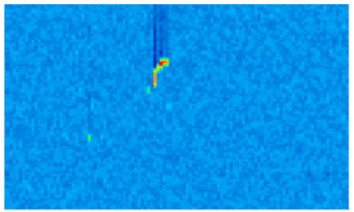
Measure solar 8-B, hep, and neutrino regeneration in the Earth with S/B>1 above 5 MeV

Reduction of radiogenic backgrounds by a factor of 100-1000 in argon; high spatial resolution and light yield





Also good for burst supernova, relic supernova

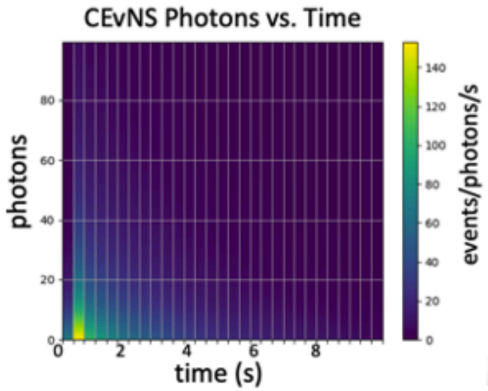


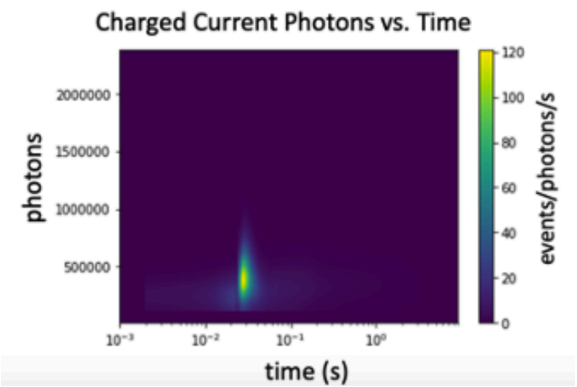
Measure all flavor components of a burst supernova flux

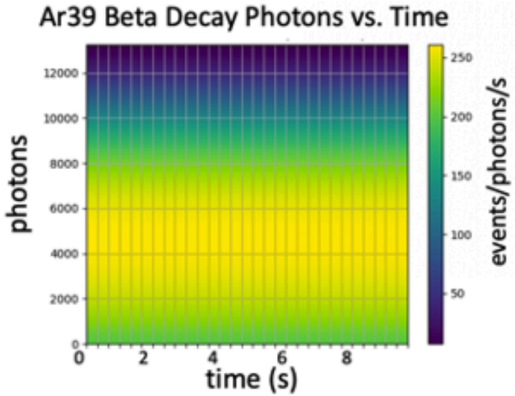
Measure SN burst neutrinos of all three flavors in real time

CEvNS glow/buzz in argon or scintillator

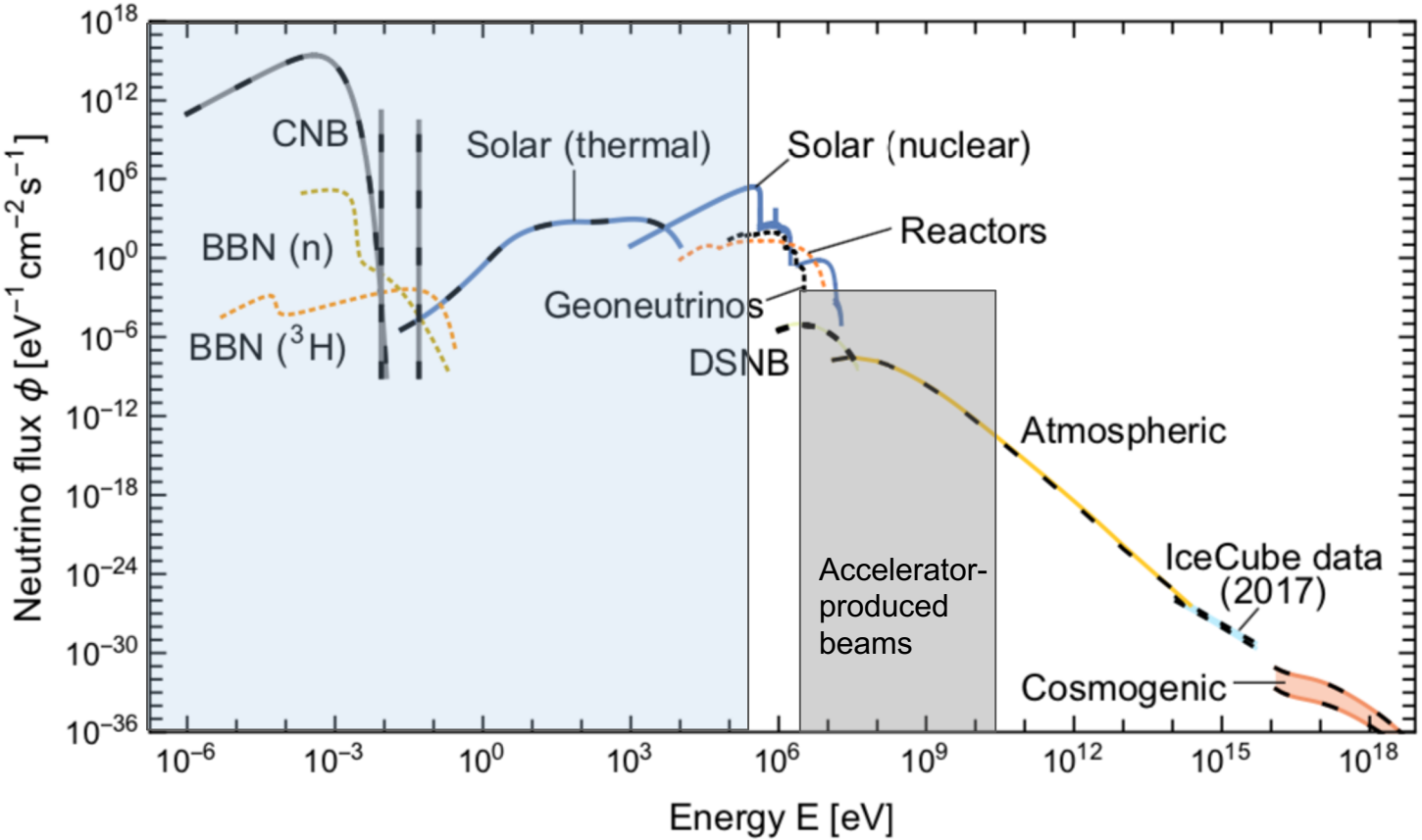
High efficiency photo-detection, reduction of radiogenic backgrounds by 100-1000







Very low energy: pp solar, geoneutrinos... and unknown territory!



Below charged-current threshold (IBD on protons threshold ~1.8 MeV)

… need elastic scattering, CEvNS, ...

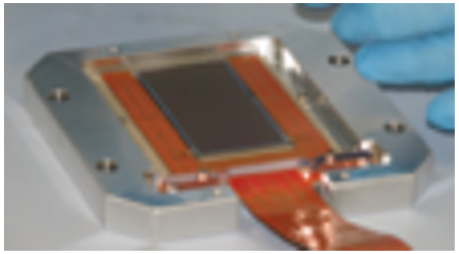
BSM physics with sub-MeV neutrino sources

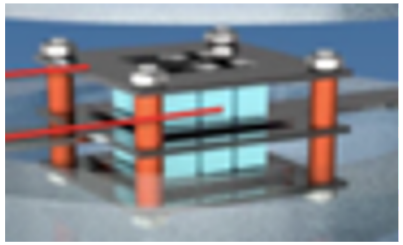
BSM physics in sub-MeV (...sub-keV) neutrinos in real time

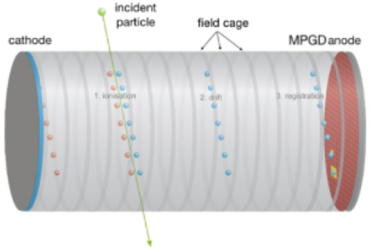
Sensitivity to very low energy CEvNS recoils in real time

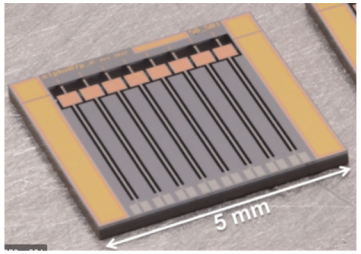
10 eV detector thresholds in multi- ton to kton-scale detectors; recoil directionality

Geoneutrinos, pp neutrinos, solar thermal, artificial radioactive source neutrinos with multiple physics applications







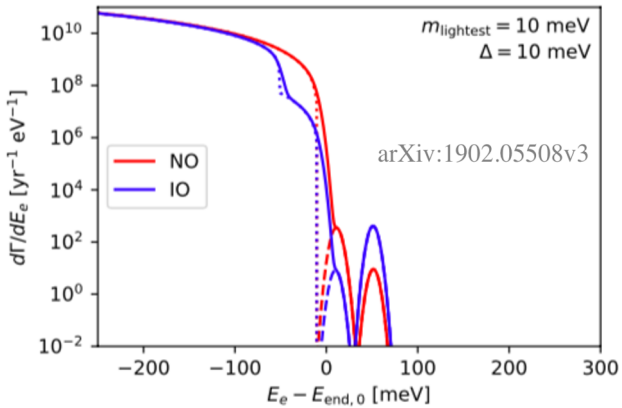


Cosmic relic neutrino background

Discover the relic Big Bang neutrinos, test of cosmologic al models

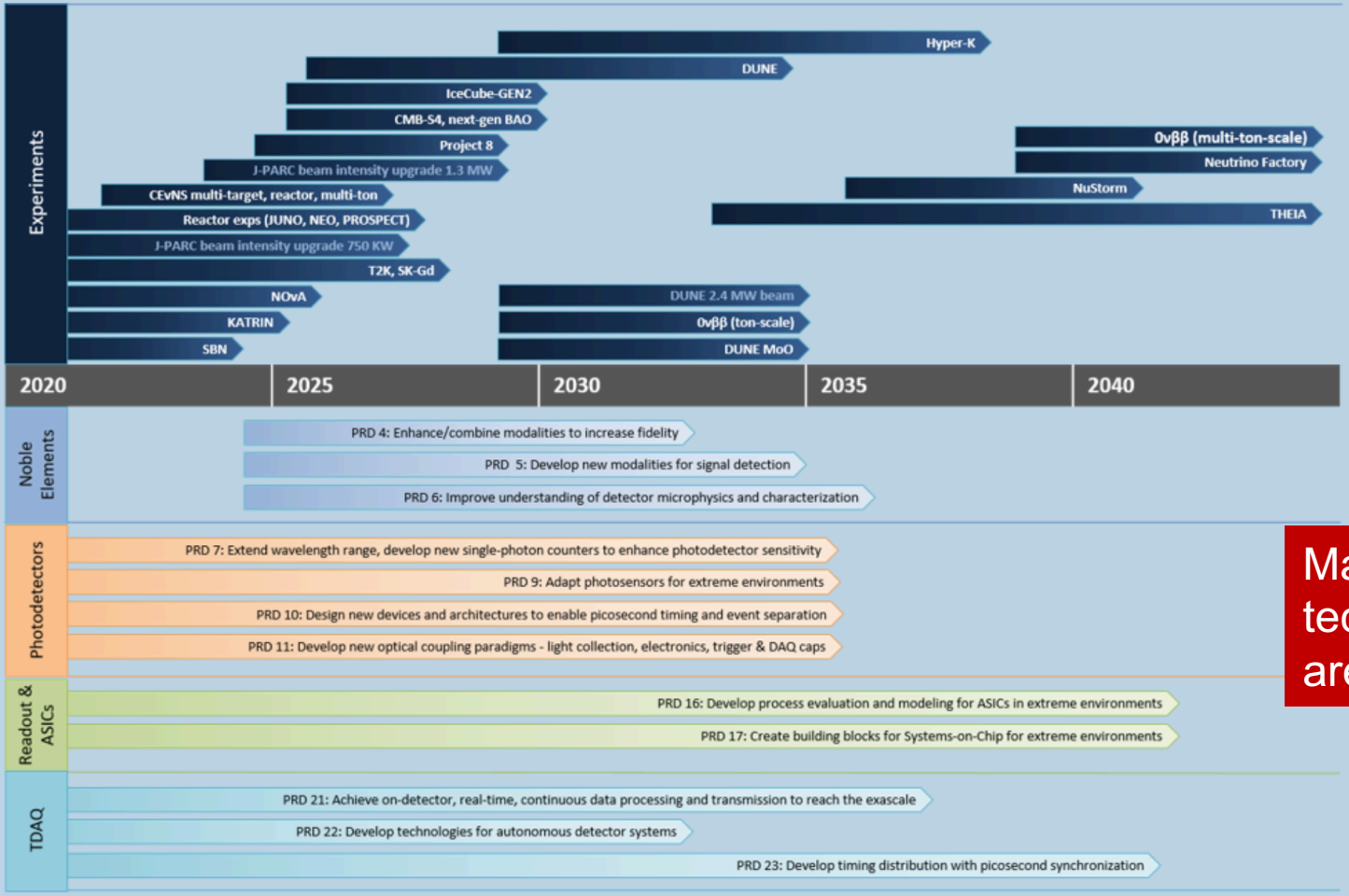
Measure cosmic neutrino capture on nuclei

10 meV energy resolution at beta endpoint; source w/ <10 meV energy loss/distortion and O(1 kg)



Neutrino Timeline

From BRN report



Many different technologies are relevant!

Summary: many ideas, much blue sky to explore...